Macroscopic traffic flow modeling and control of heterogeneous cities with multi-sensor data

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Outline

• Motivation
• Aggregated modeling with multi-sensor data
• Application to San Francisco
• Field implementation in Melbourne, Australia
• Aggregated Modeling for bi-modal networks
Motivation

Goal:
• Mitigate congestion in transport networks via appropriate control policies and by using multi-sensor data

Approach:
• Understand what causes congestion (+gridlocks)

• **Urban road networks**: Meter the input flow to the system and hold vehicles outside the system if necessary (to maintain maximum throughput, e.g. number of trip completion)

• **Motorways**: Meter the input flow to the on-ramp (merging area) and hold vehicles outside the motorway if necessary (to maintain maximum throughput in the mainline)

Walking experiment (TRAIL Conference, 2010)

- No control (nature)
- Ramp metering (control of the entrance point)
Funnel experiment

- Poor rice into a funnel using two different strategies:
  - Poor as much rice into the funnel as possible without spilling
  - Try to limit the inflow such that there is “no queue of rice”

- Which strategy is quicker or **maximises the output**?

- Funnel = **merging traffic infrastructure**

- Rice = **vehicles**

- Output = **number of trips completed**

Rice funnel experiment

![Dump all rice into the funnel on the left](image1)

![slowly pour rice into the funnel on the right](image2)

The rice passes through the right funnel much faster.
Aggregated modeling with multi-sensor data

- Fixed sensors: 500 detectors (Occupancy and Counts per 5min)
- Mobile sensors: 140 taxis with GPS; Time and position (stops, hazard lights etc)
- Geometric data (detector locations, link lengths, control, etc.)

![Graph showing maximum throughput, optimum operational point, and critical density or accumulation.]

Maximum throughput

Optimum operational point

Critical density or accumulation

Geroliminis & Daganzo, 2008, TR Part B

Problem

- A single-region city exhibits consistent aggregated traffic behavior (Macroscopic or Network Fundamental Diagram) if congestion is homogeneously distributed.

- How the concept of aggregated traffic behavior be applied to:
  - Multi-region cities with multiple centers of congestion?
  - Mixed bi-modal (cars and buses) multi-region networks?

- Can we observe a similar aggregated traffic behavior if we collect heterogeneous multi-sensor data?
Modeling: City-wide, homogeneous, single-region

- A single-region city exhibits consistent aggregated traffic behavior: **Macroscopic Fundamental Diagram (MFD)**
- Network flow \( q \) vs. Accumulation \( n \) or Density \( k \): \( q = O(n) \)

Modeling: City-wide, heterogeneous, multi-region (1)

- A **heterogeneous large-scale city** can be partitioned in a small number of **homogeneous regions**
• **A heterogeneous large-scale city** can be partitioned in a small number of **homogeneous regions**

• **Finding:** Each reservoir \( i \) exhibits an MFD with moderate scatter

• **Heterogeneity:** Each reservoir reach the congested regime at different time

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**Application: Downtown of San Francisco, CA**

- Original network (single-region)
- Clustering into 3-regions
Results: MFDs and Heterogeneity

MFD for the original network

MFDs for each reservoir

Experiments:
- AIMSUN microscopic simulator
- 4-hours demand scenario
- 10 replications R1-R10

Findings:
- MFD: RES1-RES3 exhibit MFDs with quite moderate scatter
- Heterogeneity: RES1-RES3 reach the congested regime different time

Perimeter control (non-adaptive drivers)

No control

Feedback perimeter control
Perimeter control (somewhat adaptive drivers)

No control

Feedback perimeter control

Results: Perimeter and boundary control effect

- TTS and space-mean speed are improved in average 11.7% and 15.4% respectively
- **FPC**: creates temporary queues at the perimeter of the network
- **FPC**: maintains the overall throughput to high values during rush
Results: Perimeter and boundary control effect

- Simulation with OD + DTA: improvement in average 45%
- Comparison with Bang-bang control: Improvement 10%
- **FPC:** No temporal queues at the perimeter of the network
- **FPC:** maintains throughput; respect reservoirs’ homogeneity

Field Implementation in Melbourne, AU

Stonnington area, around 120 intersections
Field Implementation in Melbourne, AU

- Progression of congestion from 7:00 am to 9:00 am

Morning peak and Partition

Evening peak and Partition
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Existence of 3D MFD for bi-modal traffic (cars, buses)

Multi-reservoir multi-modal network

Three-Dimensional vehicle MFD

Three-Dimensional passenger MFD

Geroliminis, Zheng, Ampountolas (2014) TR Part C
A 3D-vMFD for bi-modal mixed traffic

Flow-bi-Accumulation MFD = 3D-vMFD

Composition of traffic AFFECTS the shape of the 3D-vMFD

Geroliminis, Zheng, Ampountolas (2014) TR Part C

Two-region control of mixed bi-modal traffic

Ampountolas, Zheng, Geroliminis, 2016; TR Part B (under review)

Spatial variation of bus/car ratio
Two-region control of mixed bi-modal traffic

Network clustering

3D-vMFD Center
3D-vMFD Outside

Ampountolas, Zheng, Geroliminis, 2016; TR Part B (under review)

Results: Bus bunching and congestion

• Time-space diagram for bus trajectories in several public transport lines
Bus bunching phenomena

SMART TRAFFIC LIGHTS FOR 2 REGIONS

Histograms of headways for 4 bus lines

PRE-TIMED TRAFFIC LIGHTS

Other sensor data: Speed-flow relationship by NO2

Traffic flow / speed curve by NO2

Source of image Transport Scotland
Thanks for your attention!

Questions?

SASNet
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